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Projet européen MAST-3 COSINUS
Cas 1DV de Siltman
Comparaison de plusieurs modèles numériques

HP-72/2000/042/A

Documents associés : -

Résumé :

Le but de la Tâche E du Projet Européen COSINUS est de réaliser des simulations numériques, afin de tester dans les codes existants les modèles théoriques développés par les membres des autres tâches du projet. Différents cas test ont été définis, dont un cas 1DV, afin de comparer les différents modèles vis-à-vis des processus verticaux, et tout particulièrement les effets d'atténuation de la turbulence sous l'influence du sédiment. Ce document compare les résultats, dans le cas d'un écoulement permanent sans apport du lit.

La comparaison des résultats semble montrer que les deux jeux de fonctions d'atténuation retenus présentent d'importantes différences, le modèle de Munk-Anderson étant le moins atténuant. D'un autre côté, le modèle d'atténuation de Kranenburg révèle d'importantes différences entre les modèles numériques, probablement dues aux schémas numériques, en particulier au voisinage du point de saturation. Il est clair que le calcul de la vitesse de frottement près du lit est un important paramètre.

Un cas test a été réalisé sans sédiment, et un autre à partir de l'hypothèse de Rouse, qui utilise un profil de viscosité turbulente parabolique. Tous les modèles donnent de bons résultats, avec de petits écarts à la théorie, dus aux différents modèles de turbulence.

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MAST-3 COSINUS European project - Siltman 1DV case Comparison of several numerical models

HP-72/2000/042/A

Related documents: -

Abstract :

The aim of task E of the European Project MAST-3 COSINUS is to provide results using numerical models, in order to include the knowledge resulting from the other tasks. Various test cases have been defined, including a 1DV case, to compare the different models regarding the vertical processes, and particularly the modelling of turbulence damping by suspended sediment. This document is a compilation of the preliminary, in the case of a steady flow with no flux from the bed.

The comparison of the results tend to prove that the two sets of damping functions show significant differences, the Munk-Anderson model being the less damping. On the other hand, Kranenburg damping function shows strong differences between the models, probably due to the numerical schemes, particularly around the saturation. It's an evidence that the influence of the shear velocity at the bottom is an important parameter.

A test case has been done with clear water, and another one based on the Rouse assumption, which results in a parabolic eddy viscosity profile. All the codes give correct profiles, with slight differences due to the various turbulence models.

External authors: M. MARKOFSKY, O. PETERSEN, B. ROBERTS, E. TOORMAN, H. WEILBEER.

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Projet MAST-3 COSINUS - Cas 1DV de Siltman

Cmparaison de plusieurs modèles numériques

SYNTHESE

Dans le cadre du Projet Européen MAST3-COSINUS, le but de la Tâche E (*Applied Modelling*) est de réaliser des modélisations numériques, afin de tester dans les codes existants les modèles théoriques développés par les membres des autres tâches du projet. Différents cas test ont été définis.

La liste de ces cas test (Sous-tâche E.2) comprend un cas 1DV (monodimensionnel vertical), qui a pour but de comparer les différents modèles vis-à-vis des processus verticaux, et tout particulièrement les effets d'atténuation de la turbulence sous l'influence du sédiment en suspension, tels qu'ils sont pris en compte dans les codes. Ce document est une contribution à la Sous-tâche E2, qui compare les résultats fournis par les membres de la Tâche E, dans le cas d'un écoulement permanent sans apports du lit.

La comparaison des résultats semble montrer que les deux jeux de fonctions d'atténuation retenus présentent d'importantes différences, le modèle de Munk-Anderson étant le moins atténuant. Pour ces jeux de fonctions, le point de saturation n'a pas été recherché avec exactitude. Il semble que le modèle de longueur de mélange assorti des fonction de Munk-Anderson soit le plus efficace pour évaluer l'influence du sédiment sur les processus turbulents. Comparé au modèle k-ε, il minimise les effets de stratification.

D'un autre côté, le modèle d'atténuation de Kranenburg révèle d'importantes différences entre les modèles numériques, probablement dues aux schémas numériques, en particulier au voisinage du point de saturation. Les différences énormes apparaissant sur les profils de viscosité, de diffusivité et de nombre de Richardson montrent de manière claire que le calcul de la vitesse de frottement près du lit est un important paramètre pour effectuer une prédiction correcte du transport sédimentaire.

Afin d'observer la précision des codes en l'absence d'atténuation de turbulence, un cas test a été réalisé sans sédiment, et un autre à partir de l'hypothèse de Rouse, qui utilise un profil de viscosité turbulente parabolique. L'influence du paramètre de Rouse Z a été examinée. Tous les modèles donnent de bons résultats, avec de petits écarts à la théorie, dus aux différents modèles de turbulence. Une comparaison définitive demanderait des jeux de données expérimentales.

MAST-3 COSINUS Project - 1DV Siltman case

Comparison of several numerical models

EXECUTIVE SUMMARY

According to the framework of the MAST3-COSINUS European Project, the aim of task E (*Applied Modelling*) is to provide results using numerical models, in order to include the knowledge resulting from the other tasks. For this purpose, various test cases have been defined.

The list of schematic test cases (Subtask E.2) defined for Task E includes a 1DV case, in order to compare the different models regarding the vertical processes, and particularly the modelling of turbulence damping by suspended sediment already implemented in the partners' codes. This document is a contribution to Subtask E.2, as a compilation of the preliminary results provided by the different members of task E, in the case of a steady flow with no flux from the bed.

The intercomparison of the results tend to prove that the two sets of damping functions show significant differences, the Munk-Anderson model being the less damping. For these damping functions, it has not been tested when saturation occurs. It seems that the mixing-length model with Munk-Anderson functions is not the most suited to predict suspended sediment influence on turbulence. Compared to a k-ε model, it minimises the stratification effects.

On the other hand, Kranenburg damping function shows strong differences between the models, probably due to the numerical schemes, particularly around the saturation. Looking at the enormous differences in the profiles of viscosity, diffusivity and Richardson number, it’s an evidence that the influence of the shear velocity at the bottom is an important parameter to make correct sediment transport prediction.

In order to watch at the accuracy of the models with no damping, a test case has been done without sediment, and another one based on the Rouse assumption, which results in a parabolic eddy viscosity profile. The influence of the Rouse parameter Z have been examined. All the codes give correct profiles, with slight differences due to the turbulence models. A final comparison should require suitable experimental data.

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1. Introduction

According to the framework of the MAST3-COSINUS European Project, the aim of task E (*Applied Modelling*) is to provide results using numerical models, in order to include the knowledge resulting from the other tasks. For this purpose, various test cases have been defined.

The list of schematic test cases (Subtask E.2) defined for Task E includes a 1DV case (as done by **DH** [*Delft Hydraulics*] in the Siltman project [Winterwerp, 1998]), in order to compare the different models regarding the vertical processes, and particularly the modelling of turbulence damping by suspended sediment already implemented in the partners' codes.

This document is a contribution to Subtask E.2, as a compilation of the results provided by the different members of task E, in the case of a steady flow with no flux from the bed, without taking account of the improvements of the other tasks.

2. Definition of the case

2.1 General features

This idealised test case has been defined by H. Winterwerp for numerical simulations with his 1DV point model [Winterwerp, 1998]. The parameters for the simulations are the following : constant water depth of 16 m, constant velocity of 0.2 m/s, bed roughness of 10^{-3} m and a settling velocity of 0.5 mm/s. The water density is 1020 kg/m^3, and the sediment density 2650 kg/m^3. Two initial concentrations are considered (a homogeneous vertical profile is assumed) : one concentration below the saturation concentration (c_0=0.010 g/l), and one around the saturation concentration (c_0=0.023 g/l).

The equations to be solved here are :

$$\begin{cases} \dfrac{\partial u}{\partial t} + \dfrac{\partial P}{\partial x} = \dfrac{\partial}{\partial z}\left(\left(\nu + \nu_t\right)\dfrac{\partial u}{\partial z}\right) \\ \dfrac{\partial c}{\partial t} + \dfrac{\partial W_s c}{\partial z} = \dfrac{\partial}{\partial z}\left(\left(K + K_t\right)\dfrac{\partial c}{\partial z}\right) \end{cases} \tag{1}$$

in which u = velocity (m/s)

P = pressure (N/m^2)

ν = molecular viscosity (m^2/s)

ν_t = eddy viscosity (m^2/s)

c = suspended sediment concentration (g/l)

W_s = settling velocity (m/s)

K = molecular diffusion coefficient (m^2/s)

K_t = sediment eddy diffusivity (m^2/s)

The pressure term $\dfrac{\partial P}{\partial x}$ is adjusted to maintain a constant flow rate :

$$\frac{\partial P}{\partial x} = -\frac{u_*^2}{h} + \frac{\bar{u} - u_o}{T_{rel}} \tag{2}$$

in which h = water depth (m)

u_*= shear velocity (m/s)

$\bar{u}$ = computed depth-averaged velocity (m/s)

u_0 = imposed depth-averaged velocity (m/s)

T_{rel} = relaxation time (s)

2.2 Turbulence modelling

The expressions for eddy viscosity and eddy diffusivity depend on the turbulence model used for the simulations. When turbulence is modelled using a mixing-length model, ν_t and K_t are expressed as :

$$\begin{cases} \nu_t = \ell_{m0}^2 \cdot g(Ri)\left|\frac{\partial u}{\partial z}\right| \\ K_t = \frac{1}{\sigma_{t0}} \ell_{m0}^2 \cdot f(Ri)\left|\frac{\partial u}{\partial z}\right| \end{cases} \tag{3}$$

ℓ_{mo} is the mixing length, considered here to vary as a parabolic function of z ; σ_{to} is the neutral turbulent Schmidt number. Stratification is characterised by the Richardson number. Usually, the flux Richardson number is used :

$$Rf = -\frac{g}{\rho} \frac{\overline{u_i'\rho'}\delta_{i3}}{\overline{u_i'u_j'}\left[\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\right]^{1/2}} \tag{4}$$

in which the Einstein convention for summation has been used, the primes denoting the turbulent fluctuations, and δ the Kronecker symbol. Nevertheless, it's often easier to evaluate the gradient Richardson number Ri :

$$Ri = -\frac{g}{\rho} \frac{\frac{\partial \rho}{\partial z}}{\left(\frac{\partial u}{\partial z}\right)^2} \tag{4.bis}$$

Stratification effects on turbulent mixing are modelled through two sets of damping functions. On one hand, Munk-Anderson (**MA**) damping functions :

$$\begin{cases} g(Ri) = (1 + 10 \cdot Ri)^{-0.5} \\ f(Ri) = (1 + 10 \cdot Ri / 3)^{-1.5} \end{cases} \tag{5}$$

On the other hand, Kranenburg (**KR**) damping functions (1998) :

$$\begin{cases} g(Ri) = (1 + 2.4 \cdot Ri)^{-2} \\ f(Ri) = (1 + 2.4 \cdot Ri)^{-4} \end{cases} \tag{6}$$

Both assume a neutral Schmidt number $\sigma_{to} = 0.7$. This value has been chosen after computations which have been made by **DH** (*Delft Hydraulics*) with a 1DV point model, where turbulence is modelled solving the transport equation for the turbulent energy k and the turbulent dissipation ε [Winterwerp and Uittenbogaard, 1997]. Simulations have been done for different values of the neutral Schmidt number, showing that 0.7 should be the most suitable value. **LNHE** (*Laboratoire National d'Hydraulique et Environnement*) has tried simulations (with a mixing length model) for a neutral Schmidt number of 0.7 and an initial concentration of 0.023 g/l, finding computed concentration profiles in a very good agreement with **DH**'s model, although the velocity profiles were different. In addition, this value of 0.7 is in agreement with experimental data [Taylor, 1973]

The turbulent Schmidt number ($\sigma_t = \nu_t \ / \ K_t$) is thus given by :

$$\sigma_t = \sigma_{to} \frac{f(Ri)}{g(Ri)} \tag{7}$$

When turbulence is modelled through a k-ε model, the eddy viscosity is calculated as follows :

$$\nu_t = C_\mu \frac{k^2}{\varepsilon} \tag{8}$$

where $C_\mu = 0.09$. The equation on the turbulent kinetic energy k is the following :

$$\frac{\partial k}{\partial t} + u_i \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_i}\left[\left(\nu + \frac{\nu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + P + G - \varepsilon \tag{9}$$

with $\sigma_k = 1$. The production and buoyancy terms are given by :

$$P = \nu_t\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right)\frac{\partial \overline{u}_i}{\partial x_j} \qquad G = \frac{\nu_t}{\sigma_t}\frac{g}{\rho}\frac{\partial \rho}{\partial z} \tag{10}$$

The dissipation equation is :

$$\frac{\partial \varepsilon}{\partial t} + u_i \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_i}\left[\left(\nu + \frac{\nu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] + \frac{\varepsilon}{k}\left(C_{\varepsilon 1} P + C_{\varepsilon 3} G - C_{\varepsilon 2}\varepsilon\right) \tag{11}$$

in which $\sigma_\varepsilon = 1.3$, $C_{\varepsilon 1} = 1.44$, $C_{\varepsilon 2} = 1.92$, $C_{\varepsilon 3} = 1$ if $G > 0$ and 0 if $G < 0$. Production and buoyancy are still given by (10). These equations are associated to the following set of boundary conditions :

$$\begin{cases} k\big|_{z=0} = \dfrac{u_*^2}{\sqrt{C_\mu}} & k\big|_{z=Z_s} = 0 \\ \varepsilon\big|_{z=0} = \dfrac{u_*^3}{\kappa z_0} & \varepsilon\big|_{z=Z_s} = 0 \end{cases} \tag{12}$$

z_0 and Z_s being respectively the bed roughness and the surface elevation. In the case of a k-ω model, equations (9) and (11) are replaced by :

$$\begin{cases} \dfrac{\partial k}{\partial t} + u_i \dfrac{\partial k}{\partial x_j} = \dfrac{\partial}{\partial x_i}\left[\left(\nu + \dfrac{\nu_t}{\sigma^*}\right)\dfrac{\partial k}{\partial x_i}\right] + P + G - \beta^* k\omega \\ \dfrac{\partial \omega}{\partial t} + u_i \dfrac{\partial \omega}{\partial x_j} = \dfrac{\partial}{\partial x_i}\left[\left(\nu + \dfrac{\nu_t}{\sigma_\omega}\right)\dfrac{\partial \omega}{\partial x_i}\right] + \alpha\dfrac{\omega}{k}\left(P + C_{\omega 3}G\right) - \beta k\omega^2 \end{cases} \tag{13}$$

in which $\sigma^* = \sigma_\omega = 2$, $\alpha = 5/9$, $\beta = 3/40$, $\beta = 9/100$, $C_{\omega 3} = 1$ if $G>0$ and 0 if $G<0$. The eddy viscosity is then given by :

$$\nu_t = \gamma^* \frac{k}{\omega} \tag{14}$$

where $\gamma^* = 1$. Finally, boundary conditions at the bottom are modified :

$$k\big|_{z=0} = \frac{u_*^2}{\sqrt{\beta^*}} \qquad \omega\big|_{z=0} = \frac{u_*}{\sqrt{\beta^*}\kappa z_0} \tag{15}$$

For the last two models, we see that damping of turbulence occurs in the buoyancy term in the k-equation, through the Schmidt number.

3. Results and intercomparison

We will denote the members of Task E by groups of three or four letters :

- **KUL** for *Katholieke Universiteit Leuven* ;
- **HRW** for *Hydraulics Research Wallingford* ;
- **DHI** for *Danish Hydraulics Laboratory* ;
- **UHA** for *Universität Hannover* ;
- **LNHE** for *Laboratoire National d'Hydraulique et Environnement* (EDF).

Various numerical models have been used for Task E. The numerical parameters (time step, vertical discretisation) depend on the model used. Commonly, the number of horizontal layers are between 10 and

100, and several values have been tested. The computations have been done until the numerical convergence of the vertical profiles (velocity and concentration). The models are the following :

- **MIKE3 (DHI)** : runs with a mixing length model, with 20 and 50 vertical layers for the vertical discretisation ;
- **HRW's model** : runs with a mixing length model, considering 4, 16 and 100 layers ;
- **KUL's model** : runs with a k-ε model, and 100 layers ;
- **TELEMAC-3D (LNHE)** : **LNHE** used the mixing length model and 20 or 50 layers, and **UHA** developed and used a k-ω model.

In addition, in the case of c_0= 0.010 g/l, the results will be compared to *Technische Universiteit Delft* (**TUD**)'s 1DV model, running with the mixing length model.

3.1 Results with c_0=0.010 g/l

Figure 1 shows the results (velocity and concentration profiles after convergence, commonly obtained after 600 minutes) given by the different models in the case of an initial concentration c_0=0.01 g/l. In order to make the figure easy to understand, only the results computed with the maximum number of layers have been plotted. Comments about the influence of the vertical discretisation will be done later.

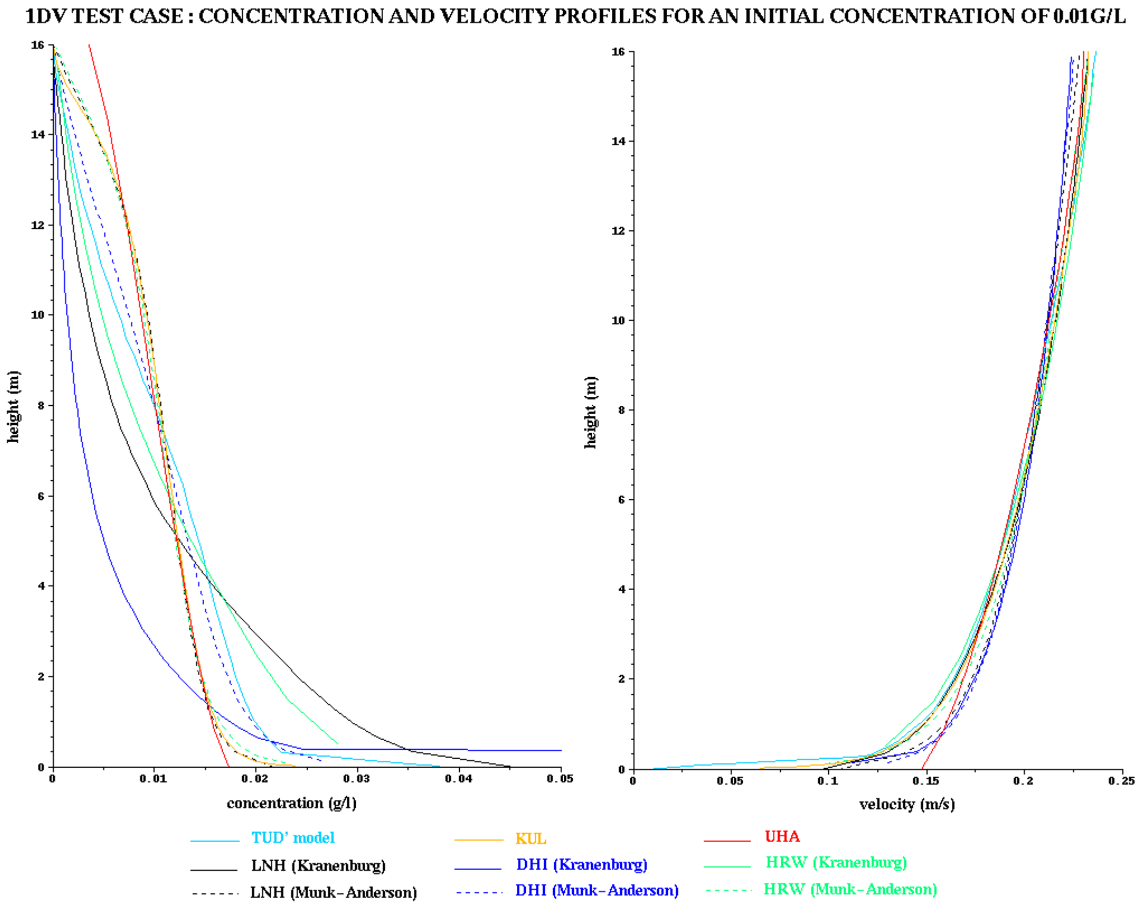

Figure 1

Regarding the velocity profiles, the figure shows a good agreement between the models. On the other hand, the concentration profiles are quite different : the models using **MA** damping functions (**DHI**, **HRW** and **LNHE**), **UHA**'s and **KUL**'s models show a good agreement, with a slight discrepancy for **DHI**'s result, which is closer to **TUD**'s model. **UHA**'s results are different from the other's near the bottom and the surface. With **KR** damping functions, the mixing length models show more discrepancies (coarse blue, black and green curves). The stratification is stronger, and surprisingly more different from one model to another one.

To understand why we observe these differences, various explanations can be drawn, but the most likely is the differences between numerical schemes, generating more or less numerical diffusion. Particularly, the shear velocity at the bottom may be strongly dependent on the scheme, especially when the grid is very coarse.

To understand better the reasons for the discrepancies, the profiles of eddy viscosity, diffusivity, and flux Richardson number have been plotted (*figures 2* and *3*). Looking at these profiles, we notice enormous differences from one code to another one. Generally speaking, the values are higher with **MA** damping. Surprisingly, the diffusivity profiles given by the **KR** damping functions match better. **UHA**'s profiles show higher values near the bed.

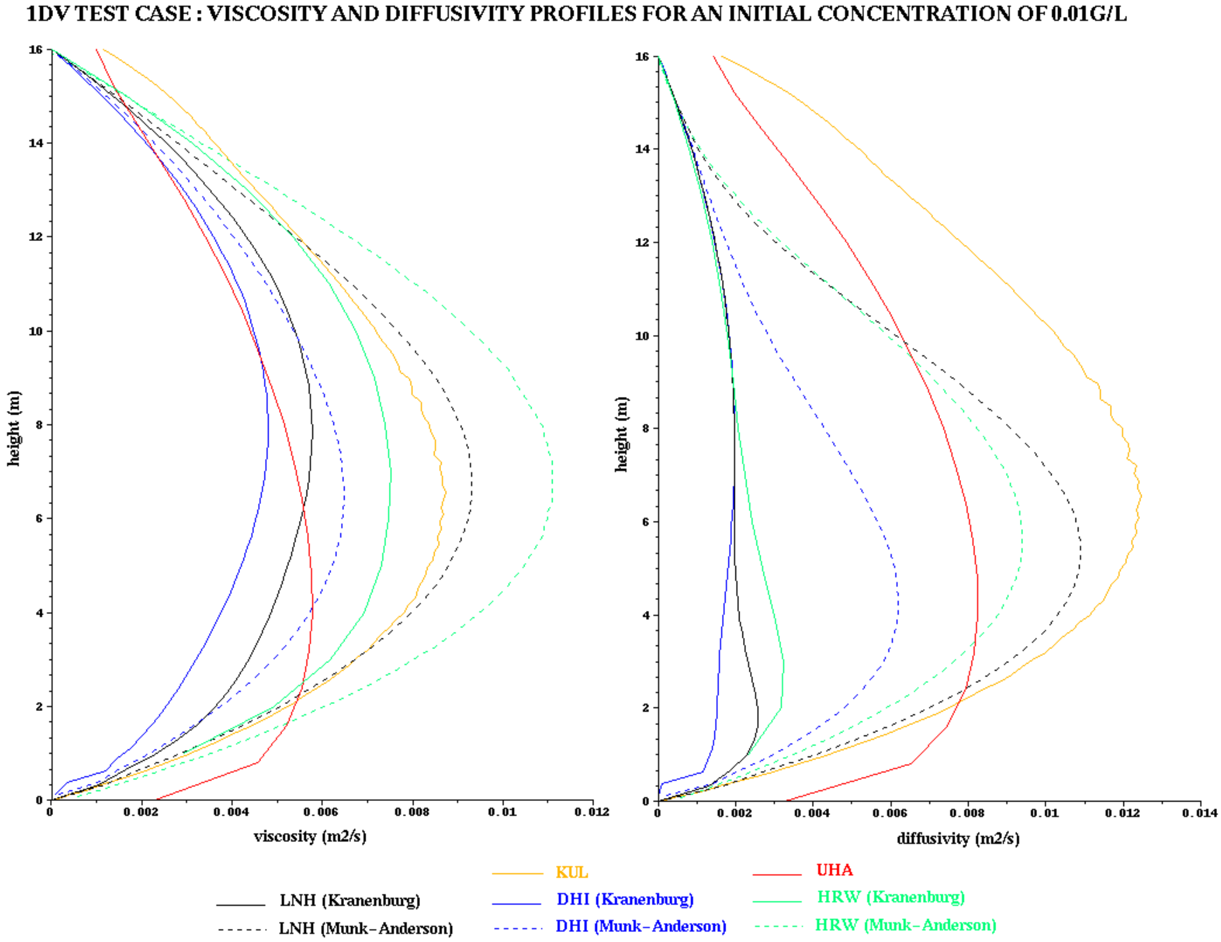

Figure 2

The previous curves show that the it's important to have a look at the turbulent parameters. Comparing the shear velocities computed by the codes, we find the following values :

Computed shear velocity u_* (m/s)	c_0=0.010 g/l MA damping	c_0=0.010 g/l KR damping or k-ε
UHA	-	0.00694
KUL	-	0.00889
DHI	0.00630	0.00530
HRW	0.00912	0.00887
LNHE	0.00782	0.00712

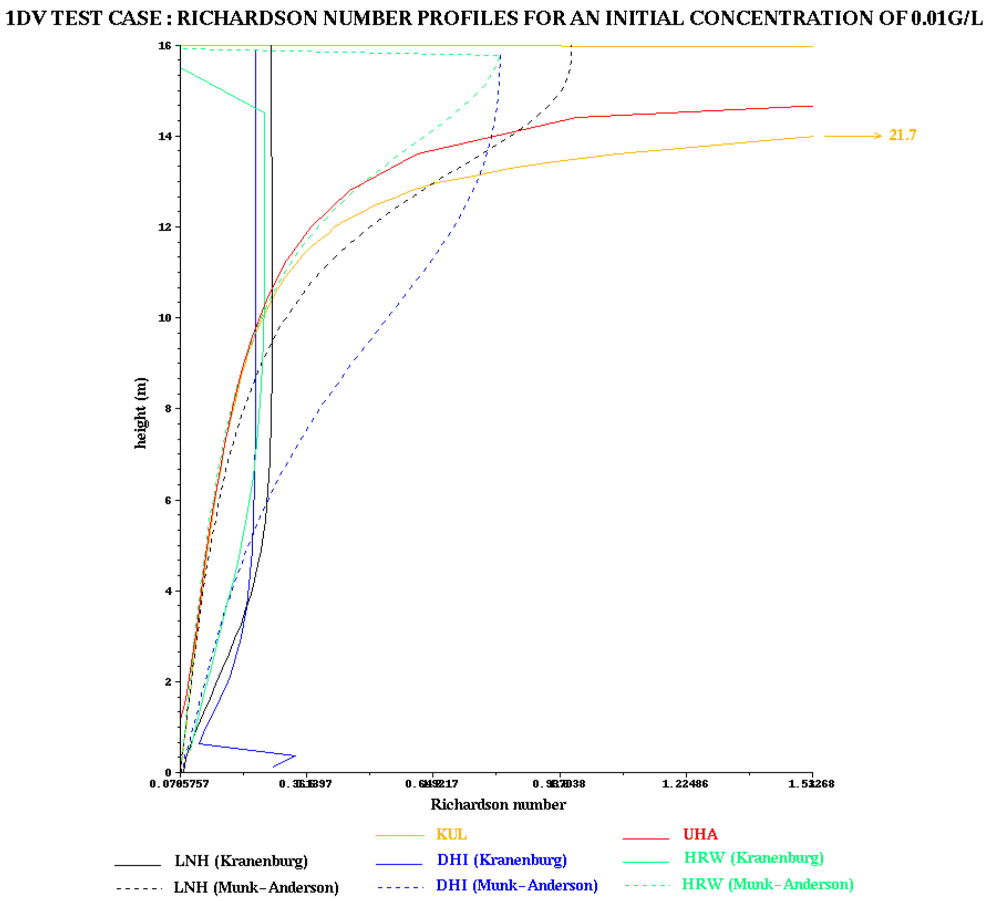

Figure 3

We see that strong differences exist again. We notice that the concentration profiles match best for the results where the value of the shear velocity matches best : **KUL**, **UHA**, **HRW** (**MA**) and **LNHE** (**MA**). It's also for these cases that the Richardson number variation match best near the bottom. As a conclusion, it seems that the correct prediction of the shear velocity is one of the most important conditions for accurate sediment transport modelling.

3.2 Results with c_0=0.023 g/l

Figure 4 shows the results in the case of an initial concentration c_0=0.023 g/l. The same comments can be done regarding the concentration profiles : **HRW** and **LNHE**'s models, with **MA** damping, show a very good agreement with **DH**'s model, while **DHI**'s model (with the same damping) is more stratified, and very similar to **UHA**'s models. On the other hand, **KR** damping gives more differences : **HRW** and **DHI**'s models are similar to **KUL**'s, and show more stratified profiles near the bottom, but stable, while **LNHE**'s profile collapses.

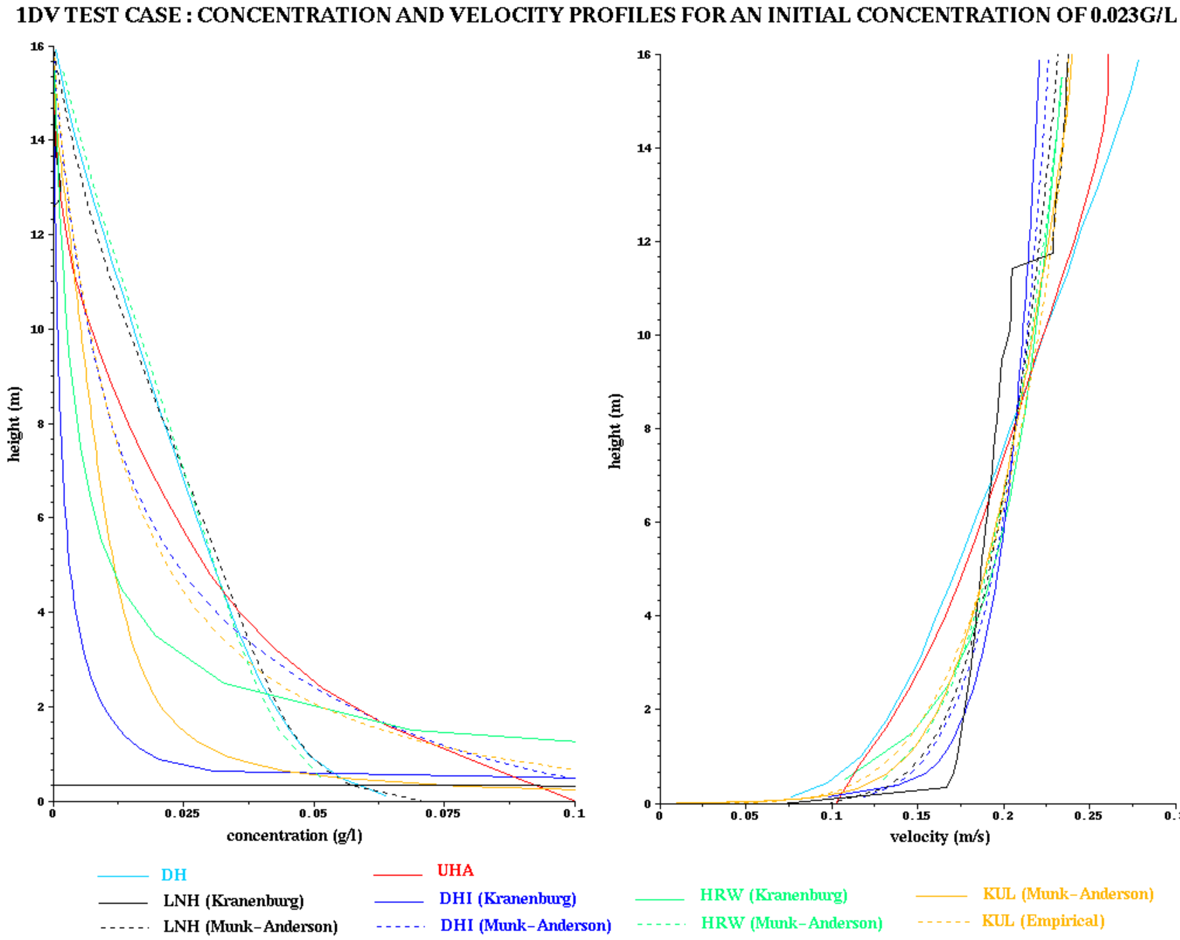

Figure 4

KUL has also tried a run with an new damping function, estimated from experimental data [Toorman, 2000] :

$$\begin{cases} g(Ri) = (1 + 100 \cdot Ri)^{-1/3} \\ \sigma_t(Ri) = \sigma_{t0}(1 + 25 \cdot Ri)^{0.8} \end{cases} \tag{13}$$

This simulation gives results very similar to **DHI**'s, regarding the concentration, viscosity and diffusivity profiles.

Another simulation has been done by **DH** (k-ε model) with an initial concentration of 0,024 g/l (not plotted on *figure 4*), and the results show that with this small increase of concentration, the flow becomes saturated and a high-concentrated near-bed layer is formed [Winterwerp, 1998]. We observe also a sudden collapse of the concentration profile (saturation effect). The reason that sometimes the profile collapses and sometimes not has been explained by Toorman [Toorman 1999], by the evolution of the shear velocity throughout the time history of the calculation. Toorman demonstrated that, for the same mean velocity, there exist two steady state solutions, one far from saturation and the other one around saturation.

The velocity profiles in *figure 4* show more discrepancies than in the case below saturation. Particularly, we see that **MA** damping functions give similar results, but more stratified than **KUL** and **DH**'s profiles. The velocity profiles provided by **LNHE** show that the saturation effect results in a very strong stratification near the bed. A possible reason to explain this numerical problem could be the fact that the **KR** damping functions do not yield a unique relationship with the flux Richardson number.

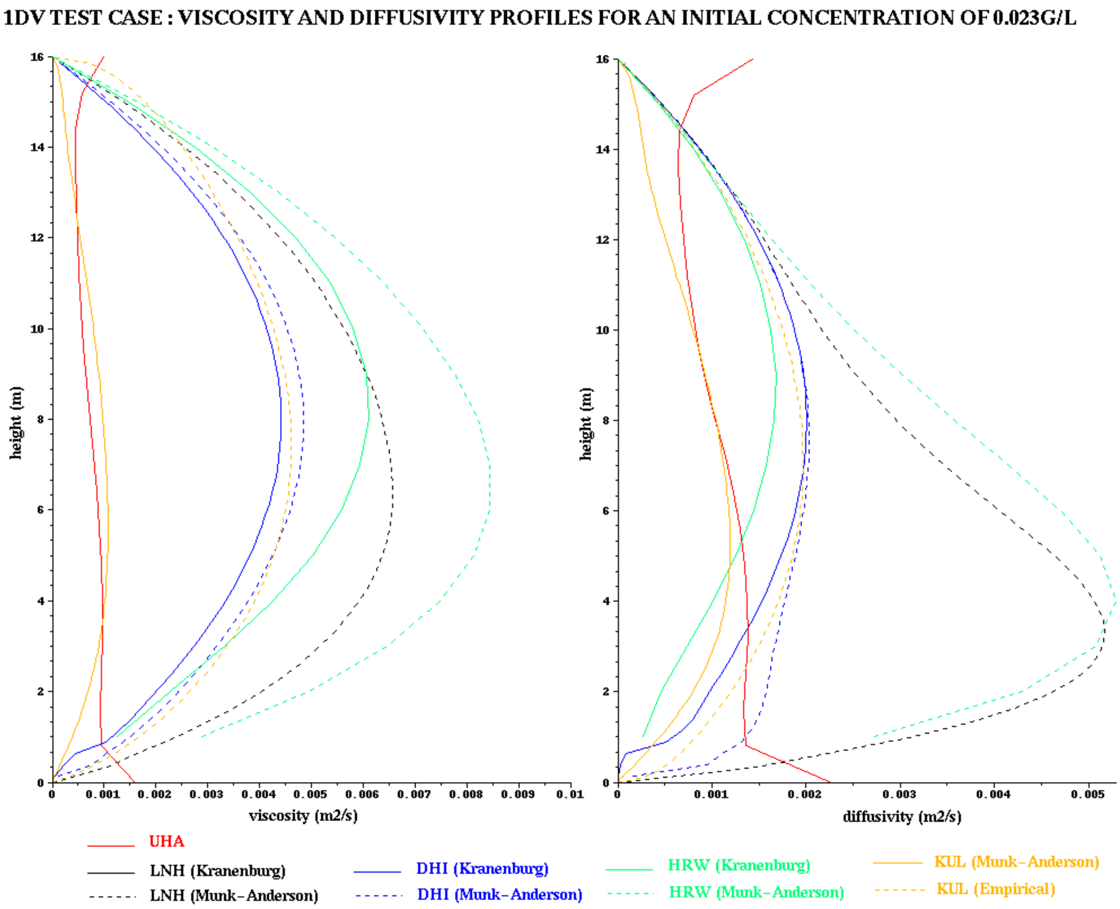

Figure 5

Like for the previous case, the viscosity, diffusivity and Richardson number profiles have been compared (*figure 5* and *6*). The profiles resulting from **LNHE**'s model have not been plotted, because they are not physical, which is due to numerical instabilities. This could result from the saturation effect. We observe, again, strong discrepancies between the models, which could result from the way in which the shear velocity is computed. As for the previous case, concentration profiles match best for the results where the Richardson number variation match best near the bottom : **KUL** and **UHA** on one hand, **HRW** (**MA**) and **LNHE** (**MA**) on the other hand.

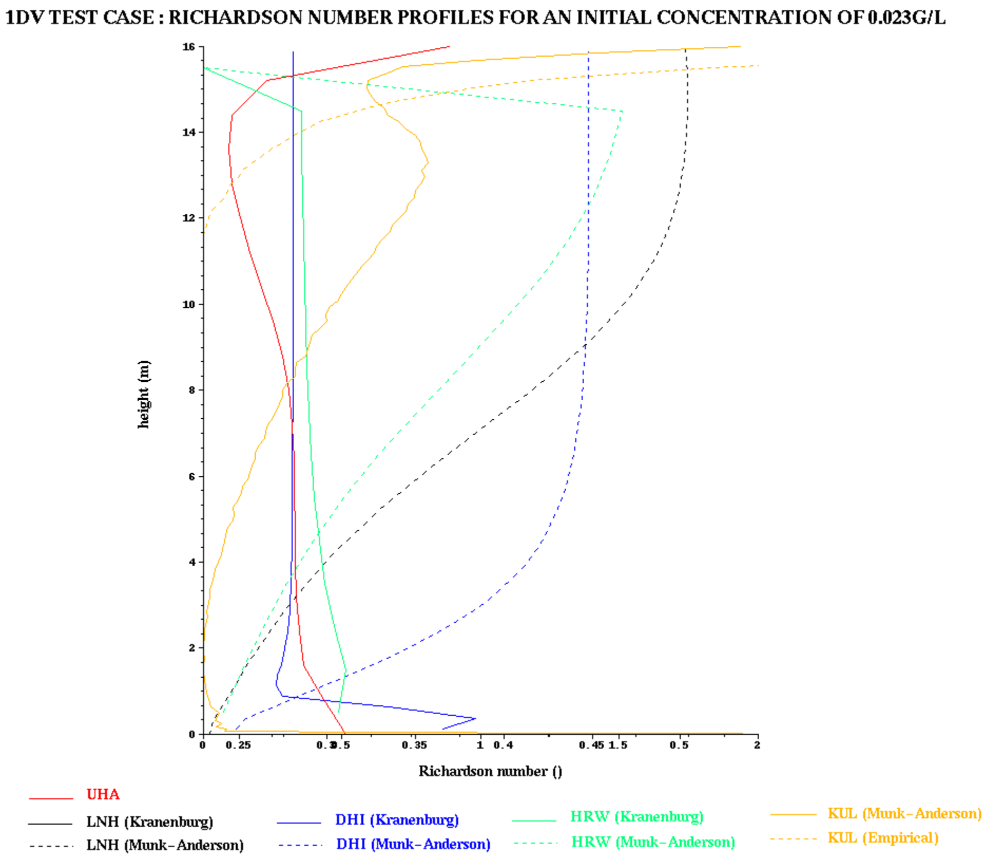

Figure 6

LNHE has compared the eddy viscosity and diffusivity given by its model to those given by **DH**'s one. The eddy viscosity given by **DH**'s model is much more reduced than in **LNHE**'s, which is due to density stratification, whereas eddy diffusivities are similar. The turbulent Schmidt number considered in the two models is indeed very different : in **DH**'s model, eddy viscosity is computed from the values of k and ε, while eddy diffusivity is deduced from the eddy viscosity, considering a constant turbulent Schmidt number of 0.7 (thus always greater than eddy viscosity). In TELEMAC-3D, however, the turbulent Schmidt number increases with the Richardson number ; when stratification occurs ($Ri > 0.3$), eddy viscosity is more important than eddy diffusivity. This explains why, using the mixing length model, the effect of stratification on turbulence (and thus on the velocity profile) is less marked. The same observations can be made when comparing TELEMAC-3D results with results obtained by J.C. Galland with his Reynold stress model [Galland, 1996].

Regarding the influence of u_* on the accuracy of sediment transport prediction, The values of the computed shear velocities show that the same comments can be done than in the previous case (with c_0=0.010 g/l, see § **3.1**) :

Computed shear velocity u_* (m/s)	c_0=0.023 g/l MA damping	c_0=0.023 g/l KR damping or k-ε
UHA	-	0.00485
KUL	-	0.00612
DHI	0.00570	0.00470
HRW	0.00868	0.00733
LNHE	0.00731	0.00538

Generally, all the models show a sensitivity to the number of vertical layers, especially when the initial concentration is around the saturation concentration. It seems that they need at least 20 layers to represent correctly the profiles. Nevertheless, we have to keep in mind that the discretisations were regular, which is not the ideal representation : it seems that refinement is needed near the bed, where the stratification is stronger and the velocity fields very sensitive to the thickness of the viscous sublayer, A coarser grid can be used close to the surface ; the best balance between speed and accuracy would be an irregular grid.

4. Test without sediment

In order to look at the ability of the models to reproduce correctly a velocity profile, and also to examine the influence of the numerical schemes, a test has been done with clear water (with the same hydrodynamical parameters). *Figure 7* shows velocity and eddy viscosity profiles provided by the models. We see that the velocities are in a good agreement with theory, given on the same figure, though they are underestimated by **DHI**. The eddy viscosity profile given by **KUL** is typical for a k-ε model, with a lower maximum and higher values near the free surface. On the other hand, **UHA**'s model show higher values near the bed. Note that **KUL** has obtained these results with a coarse grid, which can explain the deviations near the bottom.

It is important to notice that the theoretical results, following the mixing length model, does not represent the real eddy viscosity profile for open-channels either [Nezu, 1993]. Hence, the deviation of the k-ε model from the theory does not imply that the model is not accurate. As a matter of fact, we know that the k-ε model yields results closer to data measurements.

1DV TEST CASE : CONCENTRATION AND VELOCITY PROFILES FOR CLEAR WATER

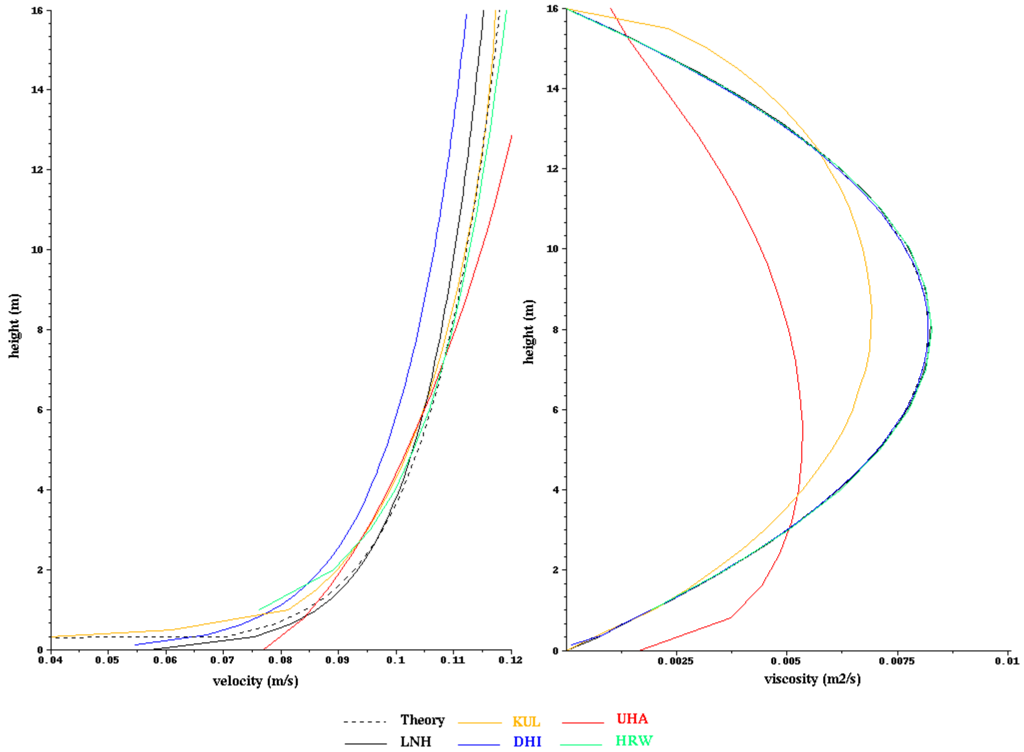

Figure 7

5. Rouse profiles

In order to study the accuracy of the models with sediment, a test case has been carried out based on the Rouse assumption, which is that there is no damping of turbulence, resulting in a parabolic eddy viscosity profile. The well known Rouse concentration profile is then given by :

$$\frac{c}{c_a} = \left(\frac{a}{z} \frac{h - z}{h - a} \right)^Z \qquad (16)$$

in which c_a is a reference concentration (here 1.0 g/l) at the reference level a (here 0.8 m), and Z the Rouse parameter : $Z = W_s / \sigma_{t0} \kappa \, u_*$. Three values of Z have been chosen : 0.5, 1 and 2. The water depth is 16 m, like in the two first cases. *Figure 8* shows the concentration profiles computed by the codes, compared to the theoretical profile given by equation (16).

We notice that all the codes give correct profiles. The reasons for the slight differences are the following : the eddy viscosity obtained with the k-ε model deviated from the parabolic profile assumed by Rouse and used in the mixing length models. The k-ε model is certainly closer to reality, as it can be seen from comparison with experimental data. Nevertheless, this difference does not affect the concentration too much there is a good agreement near the bottom, where the highest concentrations occur. We notice that the k-ε results underestimate the concentration in the upper part of the water column, where the eddy viscosity is overestimated by Rouse's theory.

ROUSE TEST CASE : RELATIVE CONCENTRATION PROFILES FOR 3 VALUES OF THE ROUSE PARAMETER

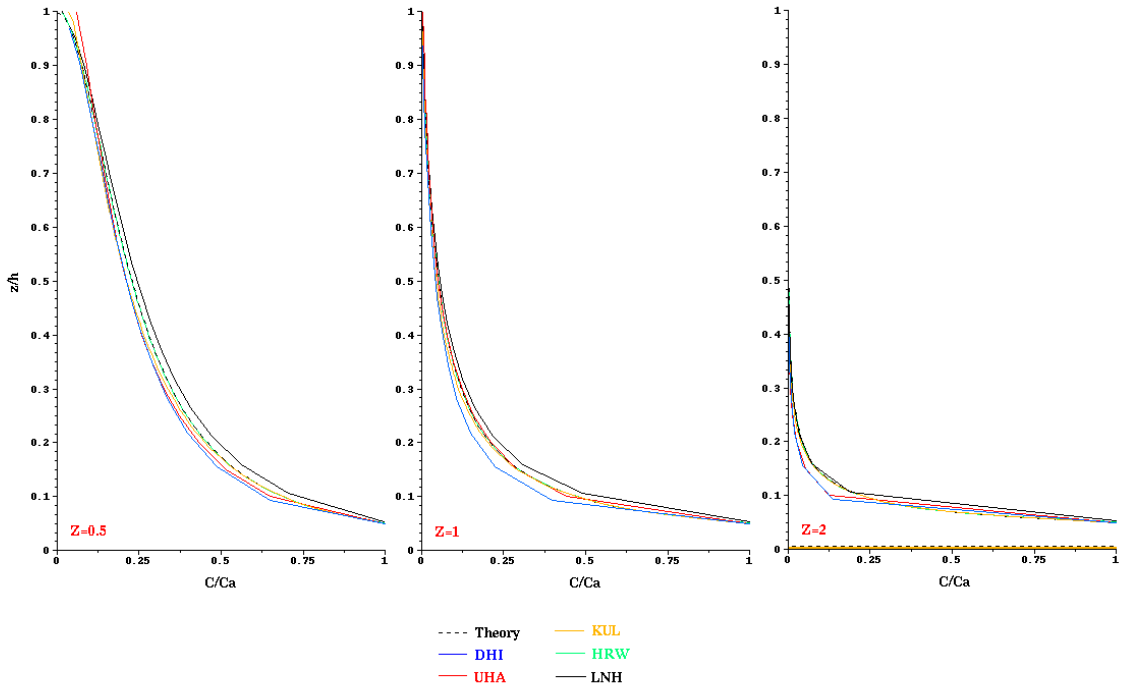

Figure 8

On the other hand, some differences can be explain by the fact that the Rouse parameter depends strongly on the shear velocity, which confirms that u_* is a fundamental parameter for sediment transport computation.

6. Conclusions

The intercomparison of the results tends to prove that the two sets of damping functions show significant differences, the Munk-Anderson model being the less damping. For these damping functions, it has not been tested when saturation occurs. It seems that the mixing-length model with Munk-Anderson functions is not the most suited to predict suspended sediment influence on turbulence. Compared to a k-ε model, it minimises the stratification effects.

On the other hand, Kranenburg damping function shows strong differences between the models, probably due to the numerical schemes, particularly around the saturation. Looking at the enormous differences in the profiles of viscosity, diffusivity and Richardson number, it's an evidence that the influence of the shear velocity at the bottom is an important parameter to make correct sediment transport prediction.

Since all the codes give correct profiles with clear water and in the case of the Rouse assumption, it is clear that the choice of damping functions may be done very carefully. A final comparison should require suitable experimental data.

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